GENERAL ENGINEERING LABORATORY

M Kingsbury

DIELECTRIC MATERIALS IONIZATION STUDY

for

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INTERIM ENGINEERING REPORT NO. 2

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GENERAL (GE) ELECTRIC

INTERIM DEVELOPMENT REPORT NO.2

FOR

DIELECTRIC MATERIALS IONIZATION STUDY

This report covers the period from August 1, 1955 to October 31, 1955

General Electric Company
General Engineering Laboratory
Schenectady, New York

NAVY DEPARTMENT BUREAU OF SHIPS ELECTRONICS DIVISION

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TABLE OF CONTENTS

GENERAL ⊛ ELECTRIC

GENERAL ENGINEERING LABORATORY

TECHNICAL INFORMATION SERIES
Title Page

AUTHOR	SUBJECT CLASSIFICATION	NO.
W. T. Starr	Corona Dielectrics	R55GL295-2
		DATE March 21,1956

TITLE

Ionization of Dielectric Materials

ABSTRACT The effects of corona on the mechanical properties and dielectric strength of several insulation materials are determined. A method involving direct electrode contact is suggested for laminates, molded and cast materials. A method in which the insulation is placed in a zone of corona between glass plates (the French cell method) is used to study some thin sheet materials.

G.E. CLASS 2	REPRODUCIBLE COPY FILED AT General Engineering Laboratory Library, Schenectady, N. Y.	NO. PAGES 25
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CONCLUSIONS Using the direct electrode contact method
(1) Phenolic paper laminate is very sensitive to erosive corona attack.
(2) Silicone glass cloth laminates were consistently poor; the glass mat-resin composites were slightly better.

In the "French Cell"
(1) The tensile strength and elongation of polyethylene are very sensitive to corona attack.
(2) Polyethylene is superior to varnished cloth in corona resistance
(3) The change of dielectric strength under 2-4% elongation with time is suggested as a measure of the corona resistance of thin films.

INFORMATION PREPARED FOR___ Navy Department, Bureau of Ships

TESTS MADE BY___ J. M. Atkins, W.T. Starr, W. Olszewski, G. Sewell, A.W. Soris

AUTHOR___ W. T. Starr *W. T. Starr*

COUNTERSIGNED___ *J A Coffman* J. A. Coffman

DIVISION General Engineering Laboratory   LOCATION Schenectady, New York

GL-16-B (4-52)

I. Introduction

Two test methods for measuring the resistance of insulation materials to corona are described in this report. It is not our intention to imply that these methods are the best that can be devised. They do, however, represent ways to study interactions between corona and insulation materials. It is more proper at the present time to consider a test method as a means for obtaining basic information than to consider it as a crystallized means for studying corona resistance. It is essential that each test method be judged on the consistency of its results with those obtained in engineering application. It is entirely possible that one type test will measure and weigh materials in one class of engineering application, while another will do this for another engineering application. For instance, one test may prove very useful in the evaluation of materials for motor insulation while another is more useful in studying insulation for dry type transformers.

It is convenient for the purposes of test to divide the test materials into two classes. One class is thin films and includes the first five in the list on page three of the first interim report. The other class includes ceramics, rubbers, cast resins, laminates, molded materials and glass mat composites. In general these materials are difficult to obtain in thin film form.

II. Corona Resistance Test Method for Laminates, Molded and Cast Materials

(Presented by the author at the ASTM Symposium on Corona Resistance, November 17, 1955)

This paper presents a test method which is yielding significant data on the corona resistance of material samples which cannot be tested in the "French Cell". Data on several materials are presented.

Corona resistance tests supplement dielectric strength testing as a means for material selection. As a matter of fact the ratio between the dielectric strength of a material as tested by fast rate of rise and by slow rate of rise, ASTM (D149-44) is now considered a measure of corona resistance. This measure, however, is recognized as very crude. A test is needed which is more meaningful. Corona resistance tests involving direct application of electrodes to the insulation material's surface have been used by others (Reference 1) as well as by ourselves and have in general given results which correlate well with service experience. These corona resistance tests involve the application of an alternating voltage stress level equal to about five times the corona starting voltage. With materials with any sort of integrity in relation to freedom from holes, the times to failure during this type of test run in the range of tens to hundreds of hours.

If a corona resistance test is to serve properly, it must define the ability of the insulation to withstand high potential and surge conditions and also must measure the ability of the insulation to operate for long

periods of time in the presence of corona. The test to be described was designed to measure these properties. In this test, an insulation slab, 0.062 ± 0.005" thick and 3 inches square is placed between two stainless steel electrodes at 15 kilovolts, rms 60 cps. This is equivalent to 242 ± 20 volts per mil.

A thickness of 1/16" was chosen for several reasons:

1. Several materials are not available in less thickness. During the procurement of materials for this contract an attempt was made to obtain materials in minimum available thickness. The 1/16" thickness was a very common minimum.

2. Laminates of 1/16" thickness are made up of several layers so that the thickness of one layer is a small percentage of the total thickness. Voids are not likely to be larger or deeper than the thickness of one lamination, unless the structure is poorly impregnated. In this case the percentage and distribution of voids determine the corona resistance of material structures. The insulation, however, should be examined carefully to determine whether it is representative.

3. The development of surface conductivity during corona aging leads to a flashover tendency which is very sensitive to voltage and ambient humidity. Larger area samples are required if voltage stress is to be kept high. If the voltage stress is lowered the time to failure becomes very long for samples much thicker than 1/16 inch.

The 15 kv chosen is well above the highest known apparatus high potential test voltage for the 1/16 inch thickness. Some materials last several hundred hours before failure at this voltage. Other materials fail immediately due to holes, inclusions and porosity. Some of these materials have desireable properties such as high temperature resistance. A separate test at 7 kilovolts is proposed for these materials. This is above the high potential test voltage based on the twice operating plus 1000 rule for an insulation 1/16 inch thick.

There are several mechanisms by which corona can cause insulation failure to occur. The most important are:

1. Corona creepage. Surface corona can cause the insulation surface to become conducting. The effective diameters of the electrodes increase until flashover occurs.

2. Corona erosion. Corona can furrow the insulation under the electrode edge until the insulation remaining becomes too thin to support the voltage.

3. Void corona. Corona within a void in the insulation can cause internal tracking with resultant rapid failure.

The amount of corona energy dissipated on the insulation surface during this type of test will be a function of the dielectric constant of the insulation material, which is also true in service.

Details of the test method are as follows:

1. Materials samples

Four samples of each material are used. Dimensions of these samples are approximately 3 by 3 by 0.062 in. Two are used as is. Into the center of each of the remaining two samples is milled a depression 3/8 in. in diameter and approximately 0.030 in. deep. The speed of the milling machine and feeding speed were coordinated to produce a smooth, flat bottomed void.

Two milling techniques were used. In one, a standard two lip end mill was used at 600 rpm. In the other, a Tungsten carbide end mill in a Precise Super 40 tool at 45,000 rpm was used.

2. Electrodes

A disc electrode 1/2 in. high by 1 in. diameter with 1/8 in. radiused edges is the high potential electrode while the ground electrode is 1/2 in. high by 2 in. diameter also with 1/8 in. radiused edges. The electrode material is stainless steel. Several electrode systems were rejected before this selection was made. Copper electrodes caused too much copper salt contamination. Nickel plated copper eroded and chemical action at the copper-nickel interface loosened the plate. A 3 in. square ground electrode of stainless steel plate was tried and rejected because of poor contact with the sample.

A picture of the sample-electrode arrangement is shown in Figure 1.

3. Fusing

A variation of the Brodhun and Perkins (1) method, described in their paper entitled "General Description and Properties of Teflon", was used. Figure 2 shows this schematically. As the sample breaks down, current flows through the dropping resistor, developing a voltage across the resistor. When this voltage becomes high enough, an arc occurs in the arc gap between the fuse wire and the point. The fuse wire breaks allowing the resistor to fall and open the circuit to the sample. The arc gap distance is critical and must be small enough to allow arcing to occur before the main circuit breakers open. A 50,000 ohm resistor and a 1 mil Advance fuse wire are found suitable. A photograph of a representative sample fusing arrangement is shown in Figure 3.

Failure time is indicated by a strip chart recording of secondary current.

4. Applied Voltage

To prevent surges, the 60 cycle voltage must be increased slowly until it reaches the test value.

5. Test results

The test results on several materials are given in Table 1.

Glass cloth base laminates are consistently poor, the glass mat base materials are slightly better, and the single phase materials are the best of the lot. We are beginning to test other materials in each class which will be much better. The tests on silicone rubber are not yet complete, but are expected to be around 1000 hours to failure.

The failure of the paper base phenolic laminate at the edge, in spite of the presence of a surface void, indicates the sensitivity of this material to erosive corona attack.

The failure of the high impact polystyrene by flashover shows that this material develops a very conducting surface quickly.

Closer adherence to a specified void depth and sample thickness is desireable, although there is no evidence that it is highly critical.

Other work is being done to determine the effect of the dielectric constants and power factor upon the corona intensity and energy. This work will define the correlation of results of this test with those of a test method such as that involving the use of the "French Cell" better than is now possible.

TABLE I

| Material | Failure Time - Hours | | | | |
| | No Void | | Void | | |
	Sample Thickness mils	Failure Time hours	Sample Thickness mils	Void Depth mils	Failure Time hours
Unplasticized Polyvinyl Chloride	63	370	63	32	120
Epoxide - Glass mat + 30%	78	20	74	28	0.2
Aluminum Silicate (ASP 400) (Amine cured)	81	1	76	27	0.1
Epoxide - Glass mat	74	13	71	26	2.1
Amine Cured	76	7	71	28	2.5
Melamine - Glass	61	1.2	59	12	0
Laminate	59	0.4	58	17	0
Silicone Resin Glass	62	0	63	23	0
Laminate - coarse weave	63	0	63	23	0
Silicone Resin Glass	65	0	64	24	0
Laminate - five weave	65	0	63	24	0
Paper base phenolic	67	146	67	25	138*
Laminate	68	225	67	28	150
High Impact Polystyrene	60	375	64	29	214**
Polyethylene	--	---	70	35	203
	--	---	70	35	330
Irrathene	--	---	70	35	240
	--	---	70	35	310

* failed at electrode edge
** failed by flashover

FIG. 1 SAMPLE-ELECTRODE ARRANGEMENT

15000 Volts

10,000 ohms

10,000 ohms

10,000 ohms

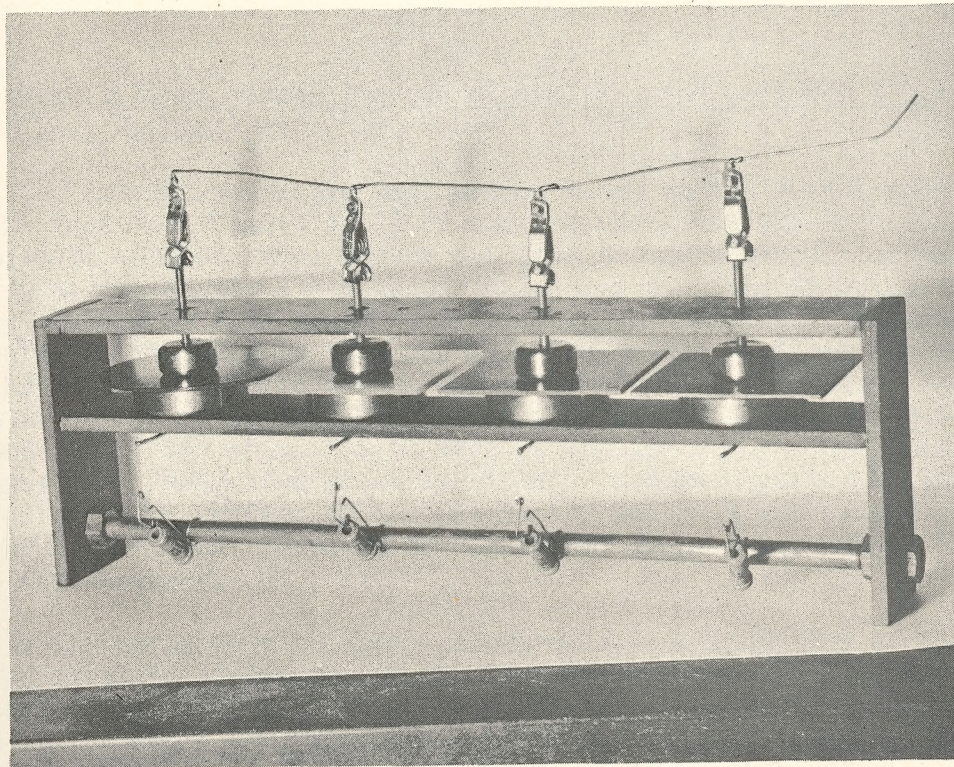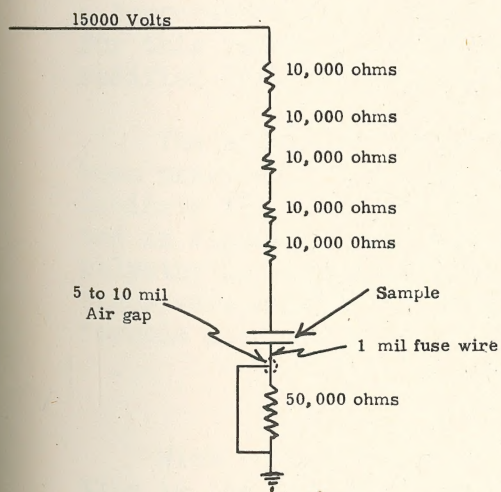10,000 ohms

10,000 0hms

5 to 10 mil
Air gap

Sample

1 mil fuse wire

50,000 ohms

FUSING CIRCUIT
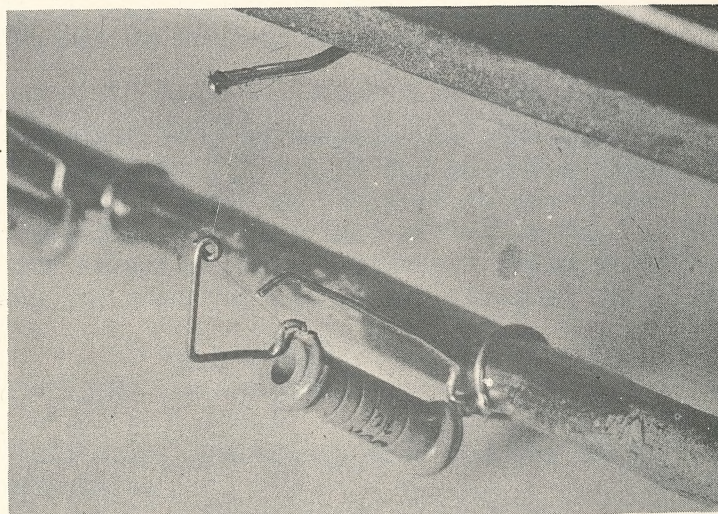
FIG. 2 FUSING SCHEMATIC

FIG. 3 CLOSE UP OF FUSING METHOD

III. <u>Observations during the use of the "French" Cell for 1/16"
Thick Insulations</u>

The corona resistance test method based on the French proposal
to the Technical Committee 15 of the International Electrotechnical
Commission applies equal corona energies to the material and measures
the chemical, physical and electrical changes in the material. It is
being studied by ASTM round robin and typical results of several ma-
terials are included in this report. The method is ideal for measur-
ing interaction between corona and materials. In this method an in-
sulation sheet is placed in an air gap 80 mils wide between two glass
plates each 1/16" thick. A voltage is applied across the glass plates,
air-gap, and insulation sheet in series. Corona occuring in the air-
gap attacks the surface of the insulation material and causes it to
change in chemical, physical or electrical properties. These proper-
ties are measured.

With insulations thinner than 16 mils, the insertion of the insu-
lation sheet in corona gap of the "French" cell causes only about five
percent change in the voltage across the gap. Insulations up to 16
mils in thickness can, therefore, be tested without changing the cell
voltage. With insulations 1/16" thick, the insertion effect is much
greater and the voltage must be adjusted to different materials. The
air-gap should be maintained constant.

Studies have been made with an 1/8" air-gap. The data obtained
thus far indicate that when 1/16" thick insulations are inserted in
the air-gap at a voltage slightly above the corona starting voltage,
a temperature rise occurs which is very dependent upon cell voltage.
For this reason it is very difficult to control the conditions in the
modified "French" cell.

The effect of dielectric constant (ϵ') on temperature rise has
been measured. The data for polyethylene ($\epsilon' = 2.3$) and melamine glass
laminate ($\epsilon' = 12$ and increases with increasing temperature) are plot-
ted in Figure 4. The voltages applied (Va) were 12.5 kilovolts for
polyethylene and 10 kilovolts for melamine glass laminate. These vol-
tages were calculated to produce the same voltage in the air-gap. The
formula used was

$$Va = 7350 \; \frac{79.2 + \dfrac{62.5}{DK}}{62.5}$$

With voltages chosen for this rule, the energy produced per unit
time is the same for the two materials.

The temperature rise can be reduced greatly by redesigning the
cell to provide for better heat transfer away from the corona region.
The measurements plotted on Figure 4 were taken at the top of the dir-
ect corona region the the center cell of a bank of 10 active cells.
These cells were made with 3 mil aluminum foil as shown in Figure 17.
The use of 40 mil Aluminum electrodes as shown in Figure 18 would help.

Temperature Rise in Modified "French" Cell

(Tests made at equal air gap voltages)

△ Melamine Glass Laminate
   at 10 kilovolts

⊙ Polyethylene at 12.5 kilovolts

W.T. Starr
General Engineering Laboratory
Feb. 20, 1956

Temperature °C

40

35

30

25

20

0   5   10   15   20   25   30   35   40

Time - minutes
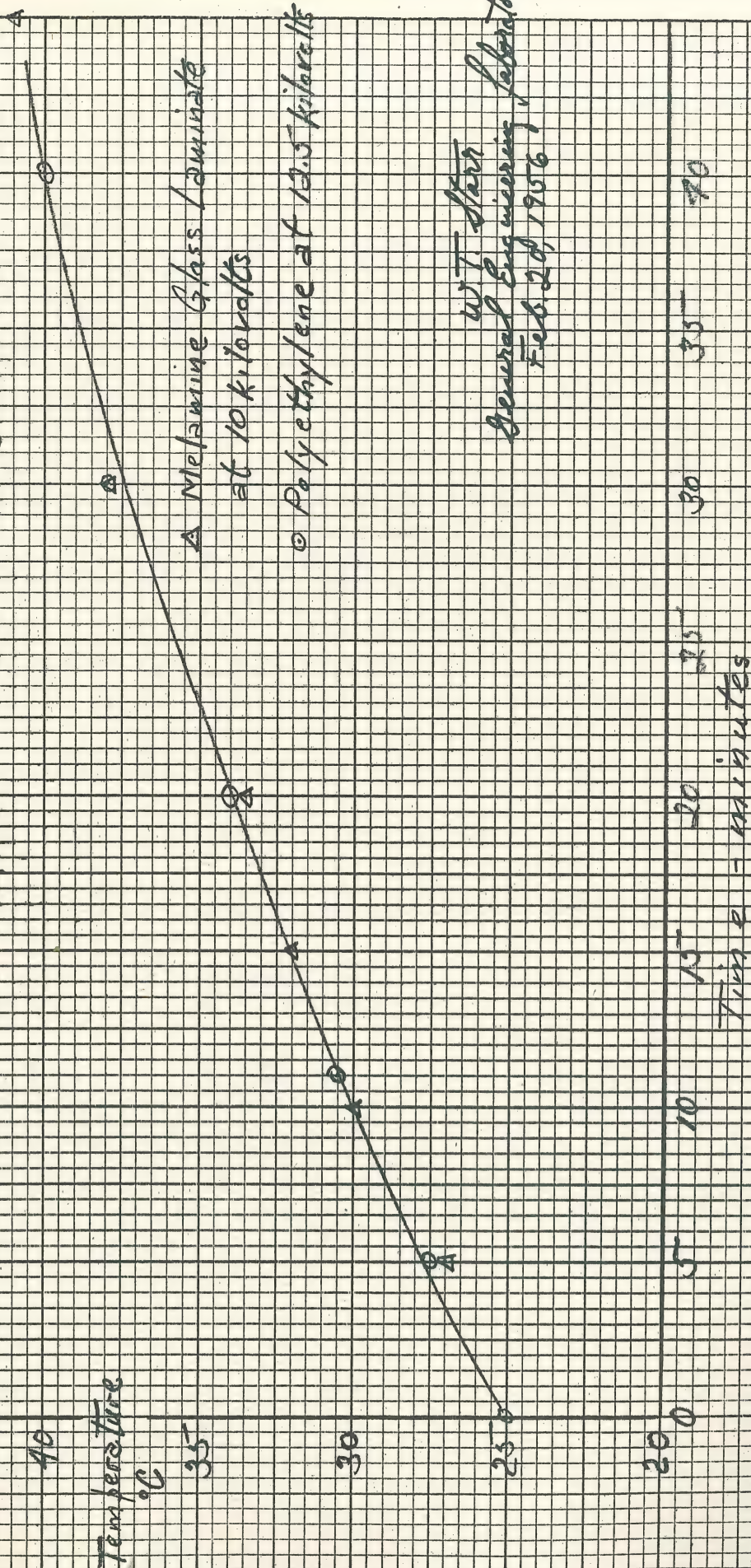
Figure 4

When the temperature problem is eliminated, a test method involving single voltage operation for all materials can be recommended. In practice the corona energy is dependent upon the dielectric constant of the insulation. Operation at constant corona energy is of academic interest only for most insulation applications.

IV. Effects of Corona on the Mechanical Properties of Mylar
   by W. V. Olszewski

One mil Mylar C samples were aged in French cells of Figure 17 construction at 7 kilovolts for various periods of time. They were then tested for tensile strength, elongation, energy to break and elastic modulus using an "Instron" testing machine. Each sample of Mylar was cut into six test areas as shown in Figure 5.

A	D
B	E
C	F

Figure 5

Samples A, B and C were exposed only to the by-products of the corona. Samples D, E and F were directly between the electrodes and were thus subjected to the direct action of the corona. The results of the mechanical testing were followed with respect to aging time to determine if sample position in the sheet (A and D compared with B and E or C and F, etc.) and, or, sample position with respect to the electrode (A, B and C compared with D, E and F) or any of their interactions were significant. The data are shown in Tables II and III.

Table II

Aging Time (hrs)	Sample	Tensile Strength (psi x 10^4)	Modulus (psi x 10^5)	Elongation (%)	Energy (in. lbs.)
Control	A	2.19	3.20	107	4.75
	B	2.14	2.96	102	4.46
	C	2.24	2.96	114	5.14
	D	2.14	3.14	100	4.38
	E	2.34	2.96	133	6.04
	F	2.28	3.02	120	5.44
2	A	2.24	3.20	192	7.77
	B	2.14	2.46	177	6.94
	C	2.06	2.46	173	6.60
	D	2.04	2.62	168	6.40
	E	2.12	2.46	179	6.97
	F	2.04	2.39	176	6.62
4	A	2.24	2.42	196	7.81
	B	2.50	2.16	187	7.37
	C	1.94	2.62	163	5.98
	D	1.96	2.46	167	6.19
	E	2.08	2.54	180	6.83
	F	1.82	2.50	150	5.25
8	A	1.84	2.67	138	5.23
	B	1.94	2.57	149	5.67
	C	2.04	2.46	159	6.10
	D	2.13	2.54	179	7.10
	E	2.00	2.54	162	6.19
	F	1.76	2.35	145	4.99
16	A	1.68	2.62	159	5.32
	B	1.92	2.62	158	5.82
	C	2.00	2.67	158	6.05
	D	1.72	2.67	149	5.06
	E	1.80	2.25	160	5.50
	F	1.81	2.35	162	5.61
24	A	2.12	2.58	173	6.85
	B	1.83	2.62	150	5.34
	C	1.98	2.60	162	6.10
	D	1.44	2.29	104	3.12
	E	1.68	2.32	157	5.13
	F	1.73	2.25	163	5.38

Test results were generally scattered and trends were not too clearly defined in the data. It was felt that some scatter might be attributed to sheet-to-sheet variation or direction of sample cutting within a sheet. "T" tests were made on additional sample groups but did not substantiate this premise. "F" tests were next made on all properties considered to find significant effects. "F" test data are as follows:

Table III

Property	Source	F	Critical F (5% Probability Level)
Tensile Strength	tE	1.92	3.33
	EP	.21	4.10
	tP	1.02	2.97
	E	5.95	4.96
	P	.76	4.10
	t	8.01	3.33
Elastic Modulus	tE	1.75	3.33
	EP	.53	4.10
	tP	1.23	2.97
	E	6.59	4.96
	P	4.76	4.10
	t	14.80	3.33
Elongation	tE	1.14	3.33
	EP	1.84	4.10
	tP	.69	2.97
	E	.45	4.96
	P	.36	4.10
	t	13.1	3.33
Energy	tE	1.57	3.33
	EP	1.49	4.10
	tP	.05	2.97
	E	1.40	4.96
	P	.34	4.10
	t	5.21	3.33

where t = time
E = position with respect to electrode
P = position in sheet

Statistical tests show that all properties are affected by length of aging although aging time does not seem extensive enough to consider samples as having mechanically failed. These tests were not carried to longer times because modifications in the cell to provide for lower temperature operation took precedence. The effects of these modifications on electrical breakdown are described in Section VII.

Figures 6 and 7 show the effects of 48, and 72 hours operation in a modified cell at 7.5 kilovolts.

In Figure 8, the average tensile and average dielectric strength results are plotted against aging time (in the direct corona region). Most of the dielectric strength results are given on page 19 of the first interim report. The dielectric strength and tensile strength values seem to be dropping at about the same rate.

Direct corona attack   By product attack

Figure 6

Direct corona attack   By product attack

Figure 7

Scale A
Lbs/in²

Scale B
Volts/mil
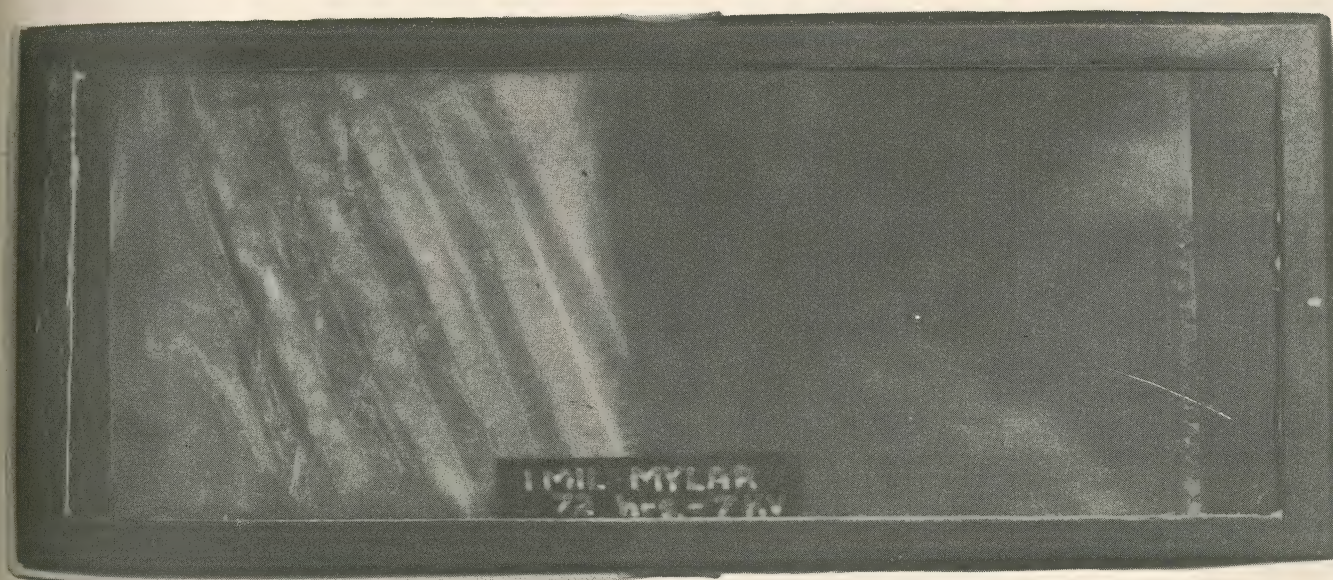
DEGRADATION OF 1 MIL MYLAR IN THE
"FRENCH" CELL AT 7 KILOVOLTS

Tensile Strength

Dielectric Strength

AGING HOURS
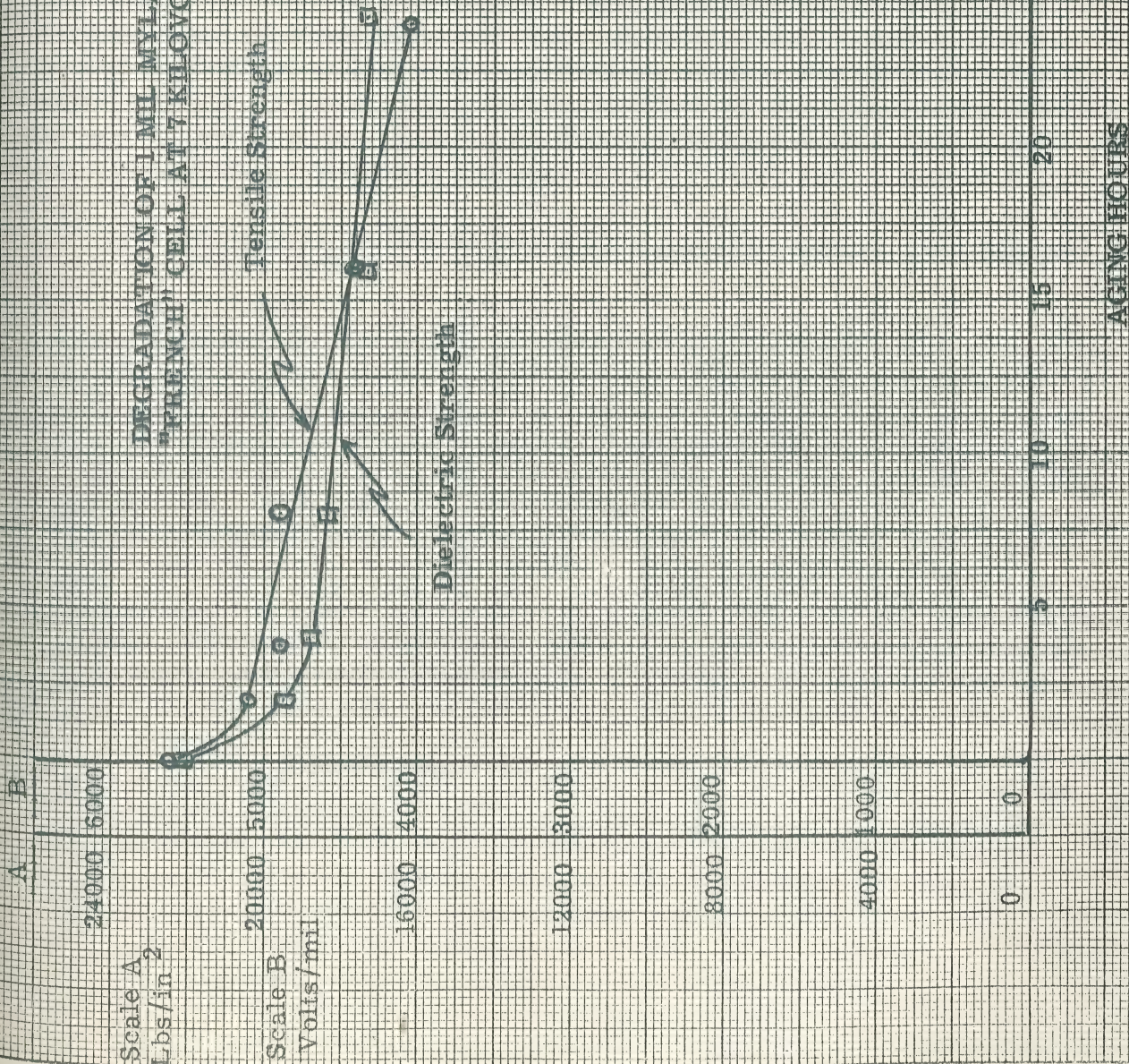
Figure 8

The statistical "F" test shows that position with regard to the electrode is significant in the case of tensile strength and modulus, although not greatly so. The effect of position on energy and elongation does not appear significant in the "F" test although the trend is in the same direction as tensile and modulus values. The fact that effect of position is generally weak seems to indicate that the degradation in the by-product area is almost as severe as it is in the area of direct corona attack.

The position of the sample in the sheet shows significance only in modulus values although, again, not a great significance. Since sheet position does not effect any other property, it may be that modulus effect is only the result of some handling or machining process and not a real test result.

Overall test results are generally inconclusive with respect to the original intent of this experiment. A concrete analysis which defines rate process, interactions, and etc., cannot be made because aging has not progressed sufficiently to crystallize trends. Further aging would be desireable, but the Mylar sticks to the cell and tears during removal at later times. Further work (Section VII) indicates that this is due to hot spots of about 45°C in this cell arrangement. Cooler operating cells do not have this disadvantage.

V. Effects of Corona on the Mechanical Properties of Polyethylene (G. J. Sewell)

Polyethylene samples were submitted for tests on the "Instron" to determine the value of mechanical tests on plastics exposed to corona. Polyethylene sheets 0.004" thick were aged in "French" cells at 7 kv. and samples cut in lots as shown in Figure 5. Samples A, B, and C were exposed to the by-products of corona in the "French" cell. Samples D, E, and F were directly between the electrodes. Tensile strength, elastic modulus, and elongation were noted with respect to aging time to determine whether sample position with respect to the electrode (A, B, and C compared to D, E, and F) or position in the sheet A and D compared to B and E and C and F, etc.) or any of their interactions were significant. Energy to break was not determined because the properties of the polyethylene forced the operator of the Instron to choose between an accurate measure of either modulus or energy. If duplicate samples were available both types of data could have been obtained.

In setting up the Instron for measurements it was noted that the values obtained depended upon the direction in which the sample was cut from the roll. The polyethylene was not isotropic. Mr. J. M. Atkins suggested that all of the test samples should be examined for orientation by placing them between polaroids. Orientation in the sheet was found to be uniform for the samples which had been aged in the cells. Test results were as follows:

Aging Time (Hrs)	Sample	Tensile Strength (PSI by 10^3)	Modulus (PSI by 10^3)	Elongation (%)
Control	A	2.65	8.33	440
	B	2.56	8.62	414
	C	2.53	8.33	348
	D	2.80	8.33	526
	E	2.57	8.33	424
	F	2.59	8.62	430
8 Hrs.				
	A	2.30	8.62	408
	B	2.52	7.69	536
	C	2.44	9.09	482
	D	2.05	7.14	343
	E	2.08	7.81	497
	F	1.88	7.35	313
24.9	A	2.10	8.06	481
	B	2.28	8.06	376
	C	2.33	7.35	393
	D	1.65	7.14	160
	E	1.61	7.69	195
	F	1.70	7.81	172
48.1	A	1.88	8.06	294
	B	2.12	8.62	330
	C	2.21	8.06	384
	D	1.42	7.58	126
	E	1.40	7.14	109
	F	1.42	7.14	116
87.0	A	1.78	8.33	242
	B	1.87	7.58	253
	C	2.04	7.58	338
	D	1.00	6.94	58
	E	0.80	5.95	44
	F	0.95	7.35	32
150.9	A	1.58	8.62	214
	B	1.62	8.62	234
	C	1.75	8.33	244
	D	0.63	7.14	15
	E	0.73	6.76	18
	F	0.74	6.81	19
180.5	A	1.64	8.33	176
	B	1.57	8.33	233
	C	1.64	7.69	240
	D	0.66	6.25	16
	E	0.65	7.14	13
	F	0.28	7.81	4
224.0	A	1.44	8.62	220
	B	1.50	8.93	248
	C	1.46	9.26	185
	D	0.34	5.95	6

Aging Time (Hrs)	Sample	Tensile Strength (PSI by 10^3)	Modulus (PSI by 10^3)	Elongation (%)
224.0	E	0.33	6.94	5
	F	0.37	6.76	7
254.5	A	1.42	10.42	118
	B	1.44	8.62	130
	C	1.56	8.62	198
	D	0.54	8.62	9
	E	0.27	7.35	4
	F	0.49	6.41	10
318.3	A	1.32	8.32	132
	B	1.40	9.26	168
	C	1.57	8.62	204
	D	0.22	8.62	3
	E	0.32	7.14	4
	F	0.38	6.14	6

Data were then analyzed by statistical methods using the "F" test, to find significant effects. "F" test data are as follows:

Property	Source	F	Critical F	(5% probability level)
Tensile Strength	EP	9.35	3.55	*
	TP	2.56	2.22	*
	TE	43.66	2.46	*
	T	425.00	2.46	*
	P	1.	3.55	*
	E	1771.00	4.41	*
Elastic Modulus	EP	1.	3.55	
	TP	1.53	2.22	
	TE	2.56	2.46	*
	T	2.51	2.46	*
	P	1.08	3.55	
	E	71.50	4.41	
Elongation	EP	2.43	3.55	
	TP	2.18	2.22	
	TE	11.95	2.46	*
	T	104.58	2.46	*
	P	1.	3.55	
	E	390.60	4.41	*

* significant

Where T = Time

E = Position with respect to electrode

P = Position in sheet

Test results were clearly defined, especially in the case of tensile strength where everything was significant except position in sheet.

In the case of elongation, variance due to time and electrode and their interaction were significant. In the modulus group the significance weak for the effect of the time-electrode interaction and time alone, but definite, as in all cases, with position with respect to electrode. Slight variance in modulus readings can be explained in the computation of elastic modulus.

$$E = \frac{Stress}{Strain.}$$

If both stress and strain were dropping in unison, modulus would stay about the same.

The apparently greater significance of sources of variance in the case of tensile strength, as contrasted with the case of elongation, is due largely to the much larger experimental error associated with elongation measurements, which include such effects as slippage in the grips and backlash in the Instron chart mechanism. This greater error in elongation measurements can be seen by comparing the actual background errors in terms of one standard deviation. The background error for tensile strength is about $\pm 2.8\%$ of the average of the initial tensile strength values. The same error for elongation is $\pm 7.6\%$ or almost 3 times greater.

Tensile strength results show significant interactions between time and position of the sheet and position with regard to the electrode. Separate data are plotted in Figure 9. Interactions between time and position in the sheet are expected from the visual observation of the effects of corona in the cell. The cells were mounted vertically so that cool air entered at the bottom of the cell and moved into the direct corona region and out the top of the window. The circulation was very slow. The temperature gradient was not more than $15°C$. Therefore, samples A and D have been subjected to higher ozone concentration than samples C and F. Averages of the tensile strength data, therefore will include the variations due to this factor.

No one single straight line fits all of the data in the direct corona region. The same is true in the region of the corona by-product attack. Two straight lines seem to produce a much better fit to the data. Since a straight line plot describing the variation of the logarithm of the property with aging time indicates a first order process, the data appeared to fit the sequential first order process described by A. L. Scheideler in a paper presented at the 1952 meeting of the Conference on Electrical Insulation. The title of the paper is "Application of Reaction Rate Concepts to Thermal Aging Studies". It is interesting to note that the zero time intercept of the second (slowest) process is at about 70% of the initial value of tensile strength, in good agreement with dielectric strength plots in Mr. Scheideler's report. The constant for the slow, life-determining processes are:

Outside the electrode - - 0.004 per hour

Under the electrode - - 0.0029 per hour

FIG. 1
TENSILE STRENGTH OF "909"
POLYETHYLENE
VS.
AGING TIME IN CORONA

G. J. SEWELL
GEN. ENG. LAB.

Figure 9

GENERAL ELECTRIC COMPANY, SCHENECTADY, N.Y., U.S.A.

160X220   29/64 Inch Divisions

CORONA DEGRADATION OF 4 MIL POLYETHYLENE
IN A FRENCH CELL AT 7 KILOVOLTS

Dielectric Strength - Run #1
Tested at 1,000 volts per sec.
slope = 24.0 volts per hr.

Run #2 - Tested at
125 volts per sec.
slope = 21 volts per hr.

Tensile Strength

Elongation

Scale A
Elongation
(per cent)

A   B
    3000

500 2500

400 2000

Scale B
Volts per mil   300 1500
      or
Lbs. per in. 2

200 1000

100   500

0   0

0   50   100   150   200   250   300

HOURS OF AGING

Figure 10

Figure 10

A linear plot of the tensile strength and elongation averages against aging time is given in Figure 10. Since elongation-to-break is a very important property in most applications, and elongations of 5% or less are indicative of a fragile material, the 4 mil polyethylene can be considered to have failed at about 250 hours.

Dielectric strength results are also plotted on Figure 10. These results are linear with time. Apparently a flaw large enough to reduce the tensile strength by a large factor produces a relatively small effect on dielectric strength. This effect as well as the initial rise in dielectric strength may be due to the grading effect that the degradation products on the insulation surface produce in the stress distribution.

VI. Effects of Corona on the Dielectric Strength of Polyethylene and Varnished Cloth

Polyethylene sheets 0.008" thick and varnished cloth (GE No. 1799) 0.007" thick were aged in "French" cells at seven kilovolts. Samples were coded as shown in Figure 11. Sixteen dielectric strength tests were made in the region of direct corona attack and sixteen dielectric strength tests were made in the region of by-product corona attack. These results are shown in Tables 6 and 7.

	Corona By Products				Direct Corona			
	1	2	3	4	5	6	7	8
A								
B								
C								
D								

Figure 11

The dielectric strength tests were made according to ASTM D-149-44. The apparatus used is that described in the appendix of ASTM D295-54T. This apparatus produces an automatic lining up of the electrodes so that their axes are parallel and controls the pressure on the electrode system. As will be explained later, our experience during this particular set of tests has led us to prefer the use of dielectric strength under elongation as a measure of corona aging.

Table 6

Polyethylene - 8 Mils

Breakdown Kilovolts

Aging Time (hrs.)	Sample	1	2	3	4	5	6	7	8
0	A	14.75	15.0	14.25	14.0	--	--	--	--
	B	--	--	--	--	15.0	14.75	17.25	18.0
	C	17.25	15.25	15.25	16.0	--	--	--	--
	D	--	--	--	--	17.0	17.0	15.75	16.5

Avg. volts -15.8

Aging Time (hrs.)	Sample	1	2	3	4	5	6	7	8
8.6	A	19.5	14.5	15.0	17.0	18.5	15.0	11.0	16.5
	B	16.0	15.0	16.0	13.0	12.25	16.0	17.0	15.5
	C	17.5	13.5	14.25	12.0	12.5	14.5	15.5	13.5
	D	16.5	13.75	14.75	14.25	12.5	18.5	15.5	15.75

Avg. volts - 15.15   Avg. volts - 15.37

Aging Time (hrs.)	Sample	1	2	3	4	5	6	7	8
26.8	A	16.5	13.5	19.5	15.5	18.0	16.5	18.5	15.0
	B	13.5	14.0	14.25	15.5	16.0	18.0	17.5	19.0
	C	17.5	16.25	14.5	14.5	17.5	17.5	17.0	17.5
	D	18.5	12.5	15.0	13.25	16.5	17.5	17.5	18.0

Avg. volts 14.64   Avg. volts - 17.34

Aging Time (hrs.)	Sample	1	2	3	4	5	6	7	8
63.0	A	18.75	18.50	16.0	17.5	17.25	13.0	16.0	16.25
	B	21.0	11.0	18.75	17.5	17.5	17.5	17.0	19.0
	C	13.0	13.25	13.25	13.5	15.0	16.0	13.5	13.5
	D	13.0	12.75	14.0	13.5	16.5	16.75	12.5	16.0

Avg. volts 15.32   Avg. volts 15.82

Aging Time (hrs.)	Sample	1	2	3	4	5	6	7	8
113.2	A	15.0	14.5	16.5	16.5	14.5	13.5	13.5	14.5
	B	16.0	15.5	15.75	15.75	13.5	12.5	13.5	13.75
	C	16.0	16.0	15.75	16.25	12.25	16.0	15.75	15.0
	D	18.0	17.0	17.0	17.5	16.0	14.5	14.0	14.5

Avg. volts 16.25   Avg. volts 17.03

Aging Time (hrs.)	Sample	1	2	3	4	5	6	7	8
144.1	A	11.50	12.90	12.50	15.10	16.3	14.95	15.6	14.0
	B	11.80	13.10	13.80	15.4	13.10	16.45	14.25	14.5
	C	12.25	13.70	13.20	13.60	15.60	13.60	14.25	17.1
	D	12.75	13.10	13.95	11.25	13.85	15.30	15.70	13.65

Avg. volts 13.11   Avg. volts 14.88

Aging Time (hrs.)	Sample	1	2	3	4	5	6	7	8
168.0	A	12.3	15.45	14.45	14.30	16.55	17.85	18.95	16.70
	B	16.15	15.70	15.15	14.15	15.75	15.45	15.75	16.85
	C	20.25	14.75	15.60	14.40	15.90	14.9	17.85	15.70
	D	22.35	19.70	14.45	12.85	15.50	15.25	13.90	14.25

Avg. volts 15.75   Avg. volts 16.06

Polyethylene (Con't)

Aging Time (hrs.)	Sample	Breakdown Kilovolts							
		1	2	3	4	5	6	7	8
213.1	A	13.90	14.90	15.20	13.40	15.15	16.55	16.05	16.35
	B	17.75	16.5	15.90	13.10	15.10	13.45	14.75	13.3
	C	16.80	15.15	15.50	14.40	16.7	17.20	15.4	13.2
	D	14.20	14.60	13.45	14.45	12.15	16.15	16.1	11.5
			Avg. volts 14.98				Avg. volts 14.94		
243.2	A	15.0	13.85	12.7	14.3	13.8	14.45	14.0	15.3
	B	16.3	13.4	14.35	15.4	15.15	13.65	15.4	13.7
	C	17.25	16.35	15.2	15.5	14.2	14.25	14.20	13.0
	D	15.8	15.20	16.45	16.90	14.0	12.40	14.20	12.0
			Avg. volts 15.24				Avg. volts 13.98		
306.0	A	13.65	13.90	14.5	13.15	13.4	13.75	13.40	11.40
	B	16.15	14.7	13.9	13.2	13.35	12.35	13.75	13.15
	C	14.50	14.90	14.3	14.35	12.0	13.60	12.5	13.20
	D	13.25	14.44	14.95	14.45	13.95	13.85	13.85	13.05
			Avg. volts 14.27				Avg. volts 13.16		
538.9	A	--	11.60	--	8.40	--	5.60	--	5.45
	B	12.2	--	11.55	--	7.0	--	6.20	--
	C	1	12.95	--	11.40	--	9.05	--	5.10
	D	12.30	--	10.00	--	--	--	6.6	--
			Avg. volts 11.30				Avg. volts 6.43		
752.3	A	15.95	--	15.2	--	5.0	--	2.85	--
	B	--	13.5	--	12.90	--	2.45	--	1.1
	C	20.0	--	12.70	--	9.65	--	7.65	--
	D	--	19.3	--	15.2	--	2.60	--	4.80
			Avg. volts 15.59				Avg. volts 4.51		

Table 7

#1799 Cable Cloth - 7 mils
dusted with mica dust.

Aging Time (hrs.)	Sample	Breakdown Kilovolts							
		1	2	3	4	5	6	7	8
0	A	15	11.5	13.75	13.25	---	---	---	---
	B	---	---	---	---	11.0	14.5	14.0	14.0
	C	10.75	13.5	12.5	---	---	---	---	---
	D	---	---	---	---	10.25	12.5	12.5	12.5

Avg. volts 12.77

7.8	A	12.65	12.40	11.8	11.65	10.7	10.05	9.35	8.3
	B	12.15	10.7	10.9	12.0	10.45	9.35	9.45	9.9
	C	11.65	11.75	11.35	11.80	10.85	9.60	8.00	8.6
	D	11.65	11.70	11.65	12.30	12.10	9.85	9.65	9.8

Avg. volts 11.75   Avg. volts 9.75

23.4	A	12.65	12.30	11.75	12.20	8.75	8.0	9.1	9.1
	B	10.30	10.30	11.50	12.35	9.20	8.6	8.3	9.7
	C	11.80	11.80	11.50	11.85	9.70	7.50	6.75	8.9
	D	12.50	12.15	11.90	12.45	9.70	9.15	8.45	8.75

Avg. volts 11.83   Avg. volts 8.73

63.0	A	12.5	12.25	14.0	13.5	10.5	9.5	9.0	8.5
	B	12.0	10.25	13.75	13.25	9.0	8.0	8.0	7.75
	C	12.75	11.75	12.5	13.0	9.5	8.5	8.75	10.0
	D	10.5	11.5	13.25	13.75	8.25	6.7	9.25	8.25

Avg. volts 12.53   Avg. volts 8.72

86.4	A	11.40	10.95	11.05	9.05	5.15	5.25	5.30	5.95
	B	11.65	11.15	10.70	10.90	6.70	7.15	6.25	5.80
	C	11.80	10.45	11.10	11.15	7.30	5.50	6.40	5.75
	D	7.25	11.70	11.65	11.00	6.85	6.00	6.10	6.45

Avg. volts 10.81   Avg. volts 6.12

#1799 Cable Cloth-7 mils (Con't)

Aging Time (hrs)	Sample	Breakdown Kilovolts							
		1	2	3	4	5	6	7	8
109.7	A	10.45	10.55	10.65	9.25	5.90	5.10	5.75	3.7
	B	11.60	10.85	11.00	9.65	6.40	6.00	5.20	5.10
	C	12.10	11.25	9.25	10.70	6.15	2.6	5.10	5.10
	D	9.70	11.75	11.80	10.90	6.75	5.25	3.80	5.20

Avg. volts - 10.72   Avg. volts - 4.58

Aging Time (hrs)	Sample	1	2	3	4	5	6	7	8
144.8	A	10.10	8.85	7.10	6.25	5.85	5.15	5.00	2.2
	B	10.35	9.85	8.85	8.20	6.30	5.10	5.45	2.6
	C	10.85	10.05	9.7	9.30	6.60	5.25	5.05	1.75
	D	11.15	10.55	9.85	9.80	7.25	2.45	4.55	2.70

Avg. volts - 9.43   Avg. volts - 4.58

Aging Time (hrs)	Sample	1	2	3	4	5	6	7	8
205.2	A	9.85	7.90	5.05	5.0	5.35	1.70	2.45	1.45
	B	10.15	9.40	8.20	4.45	2.40	5.80	3.60	2.00
	C	11.75	10.60	9.30	7.30	2.20	5.25	1.70	1.85
	D	12.00	11.15	9.95	8.95	5.00	6.35	5.15	2.80

Avg. volts 8.81   Avg. volts - 3.44

Aging Time (hrs)	Sample	1	2	3	4	5	6	7	8
243.1	A	11.55	8.45	7.30	5.40	4.20	5.10	2.00	4.85
	B	11.45	9.50	4.90	5.40	5.05	5.40	2.75	1.70
	C	11.75	11.10	9.45	6.45	5.15	5.05	0.95	1.95
	D	13.10	10.50	9.85	8.50	2.00	3.90	4.90	5.30

Avg. volts - 9.04   Avg. volts - 3.77

Aging Time (hrs)	Sample	1	2	3	4	5	6	7	8
306.0	A	7.00	6.70	5.25	6.15	5.1	1.75	2.3	4.1
	B	8.85	7.15	6.75	7.05	5.15	1.75	5.15	1.7
	C	10.50	9.35	7.30	7.70	6.65	5.7	6.50	5.4
	D	12.25	10.95	9.70	7.95	7.15	4.40	6.10	2.35

Avg. volts - 8.16   Avg. volts - 4.45

Aging Time (hrs)	Sample	1	2	3	4	5	6	7	8
546.9	A	3.50	--	2.90	--	4.50	--	4.70	--
	B	--	4.35	--	4.50	--	4.20	--	2.25
	C	7.80	--	5.55	--	5.05	--	4.20	--
	D	--	10.00	--	5.55	--	2.65	--	3.5

Avg. volts - 5.52   Avg. volts - 3.88

Aging Time (hrs)	Sample	1	2	3	4	5	6	7	8
758.0	A	2.0	--	1.0	--	1.45	--	1.15	--
	B	--	4.45	--	1.2	--	1.0	--	1.1
	C	0.95	--	0.90	--	1.6	--	1.0	--
	D	--	8.0	--	5.9	--	1.0	--	0.85

Avg. volts - 3.05   Avg. volts - 1.14

The averages of the breakdown results for the direct corona region are plotted against aging time in Figure 12. Dielectric strength of polyethylene drops almost linearly with time to about 500 hours. The dielectric strength of the varnished cloth drops very rapidly at first and then levels off so that after about 200 hours it loses very little dielectric strength even up to 600 hours or so. The maintenance of dielectric strength of polyethylene in the first period of aging up to 300 hours is probably the most important factor in the comparison of materials. This places polyethylene far ahead of varnished cloth. Moreover, as the 1799 cable cloth aged in the cell, it was noted that that section of material which was under the electrodes became increasingly brittle. Were the material tested under a slight elongation, cracking of the varnished film would have opened up paths thru the material which would cause a marked lowering in the dielectric strength. It is believed that this would have resulted in failures at about 250 hours. In this connection, it is interesting to note that one of the ASTM specifications for acceptance of varnished cloth is its dielectric strength under elongation

Mr. Dexter and Mr. Christensen of the Dow Chemical Company have advocated the use of the dielectric strength measured on a mandrel which produces a 2% elongation in the outer fibers of the material being tested as a good criterion for studying varnish films. We have obtained the plans for such an electrode system from Mr. Christensen, and are now tooled to make such measurements.

An examination of the data in Table 7, relating to the dielectric strength measured in positions A 3 and A 4 compared to the dielectric strength in the rest of the by-product attack region will show that the material in this particular region tended to degrade faster than the material in other parts of the by-product region. This fact indicates that most of the degradation occurring in this type of test is due to ozone attack.

Since the distribution of breakdown strength results is as important in defining the insulation quality as is the average, some representative distributions are shown plotted on extreme value paper in Figure 13. There is a strong tendency for the data on unaged and moderately aged material to fit a straight line, up to over 100 hours of aging. The deviation from a straight line is only slight even at 306 hours. Between 306 and 539 hours, however, the distribution changes. The material at 539 hours is not uniform. At this time the dielectric strength is dropping so fast that interactions between aging time and position of the test area with respect to the electrode are amplified. This is apparent in the data of the table on page 16. The test results obtained in position 5 tend to be higher than those in positions 6, 7, and 8.

This amplification of interactions during the rapid drop of dielectric strength is common to many materials. The data on varnished cloth and Mylar show this effect. Improvements in cell construction and methods for mounting the samples in the cell can be made which will reduce these interactions. However, conditions in the direct corona zone cannot be con-
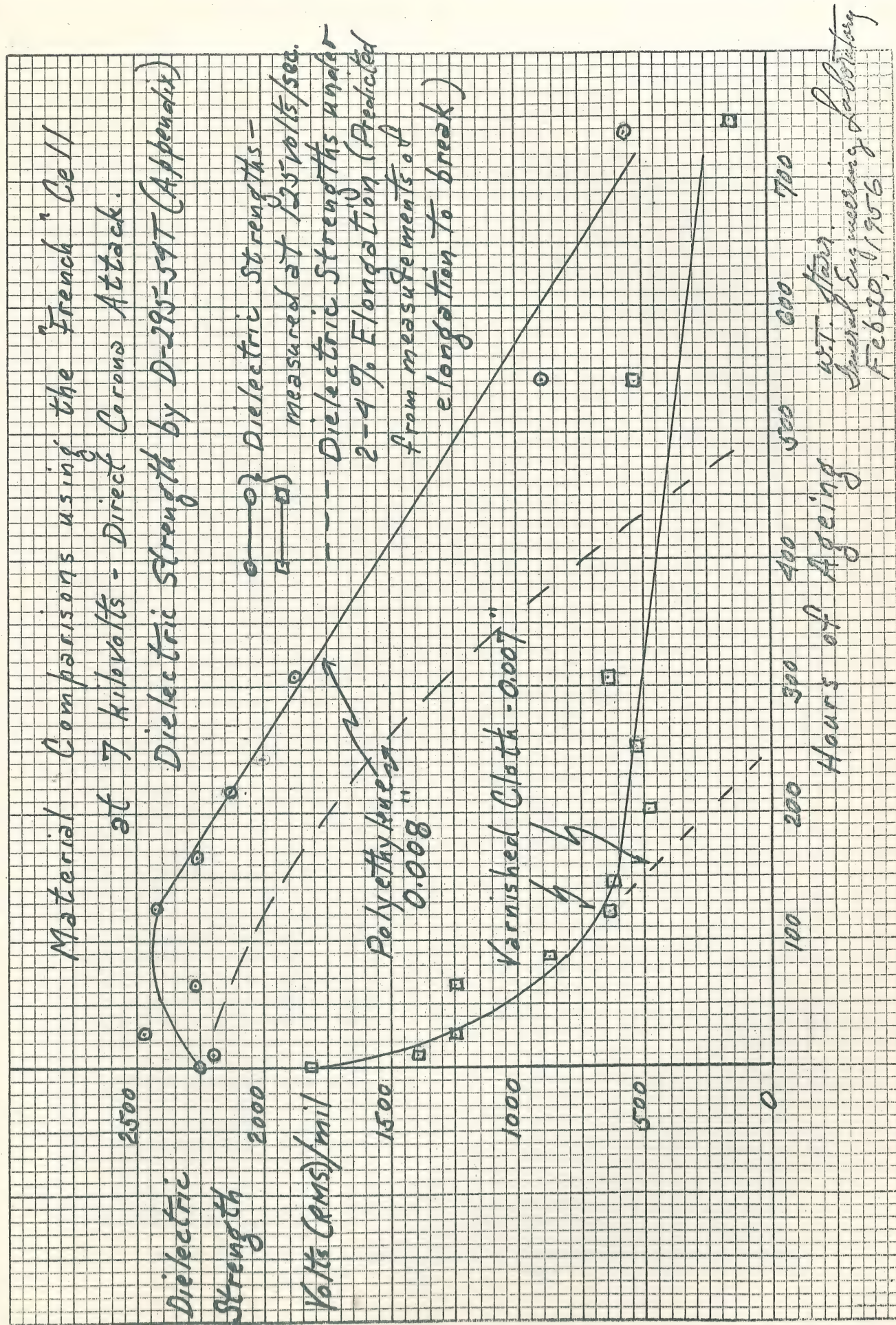
Material Comparisons using the "French Cell"

at 7 kilovolts - Direct Corona Attack.

Dielectric Strength by D-295-39T (Appendix)

o-o Dielectric Strengths - measured at 125 volts/sec.
□-□ Dielectric Strengths under
--- Dielectric Strengths under
2-4% Elongation (Predicted from measurements of elongation to break)

Dielectric Strength Volts (RMS)/mil

2500
2000
1500
1000
500
0

Polyethylene 0.008"

Varnished Cloth -0.007"

100   200   300   400   500   600   700

Hours of Ageing

W.T. Stern
General Engineering Laboratory
Feb 10, 1956

Figure 12

Figure 12

Figure 13

Dielectric Strength of 0.008" Polyethylene vs.
Ageing Time in the "French" Cell at 7 Kv.

RETURN PERIOD

Kilovolts
60 cps. RMS.

27 hrs.

O(x), 63(△), and 168(O)hrs.

243 hrs.

306 hrs.

probable 450 hrs.

539 hrs.

750 hrs.

FREQUENCY
REDUCED VARIATE

W.T. Starr
Research Engineering
Laboratory
General Electric Co. Feb 2,'51

Figure 13

Corona Degradation of 4 mil Polyethylene in a "French Cell" at 7 Kilovolts – Dielectric Strength in the Direct Corona Region – Run #2
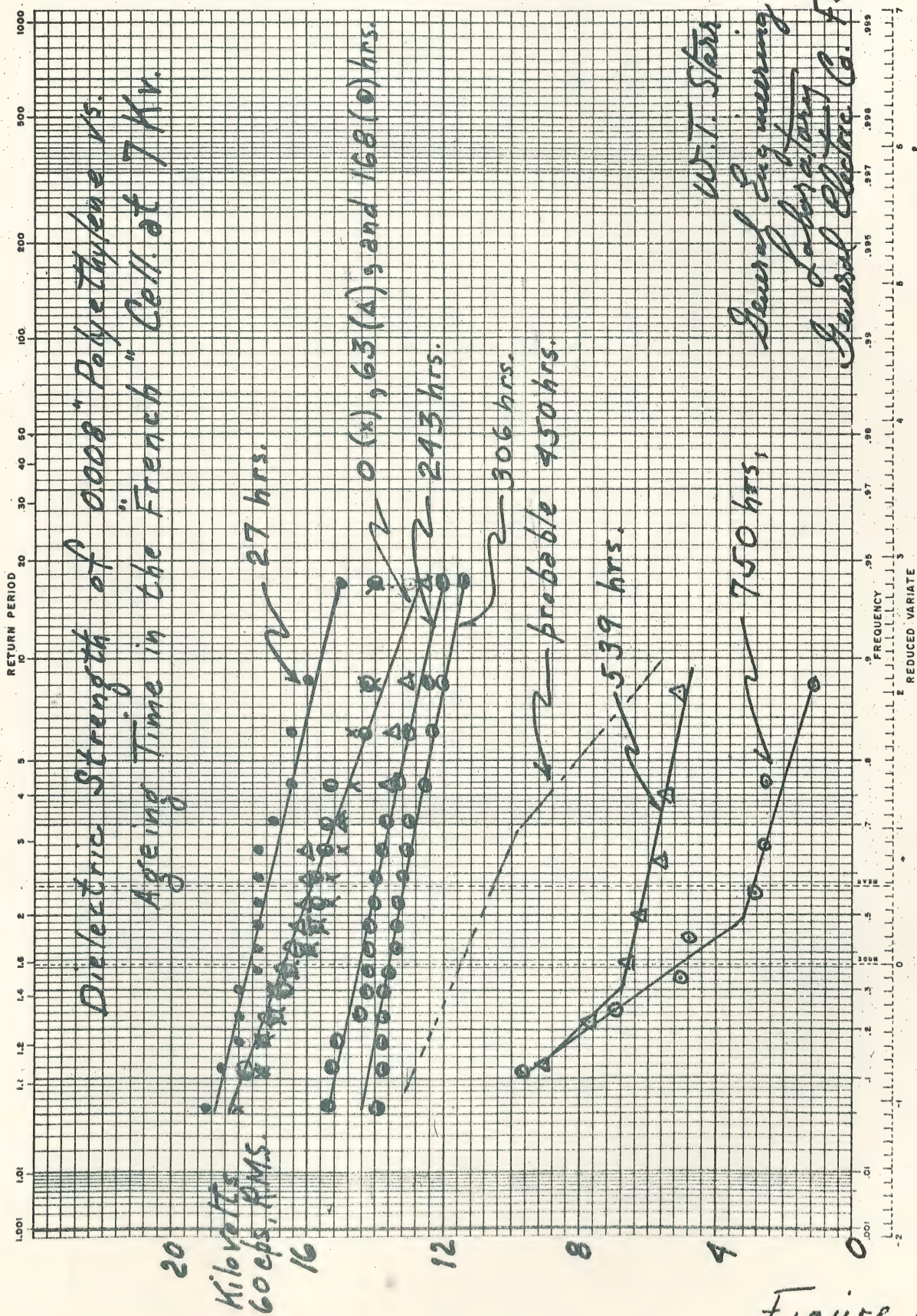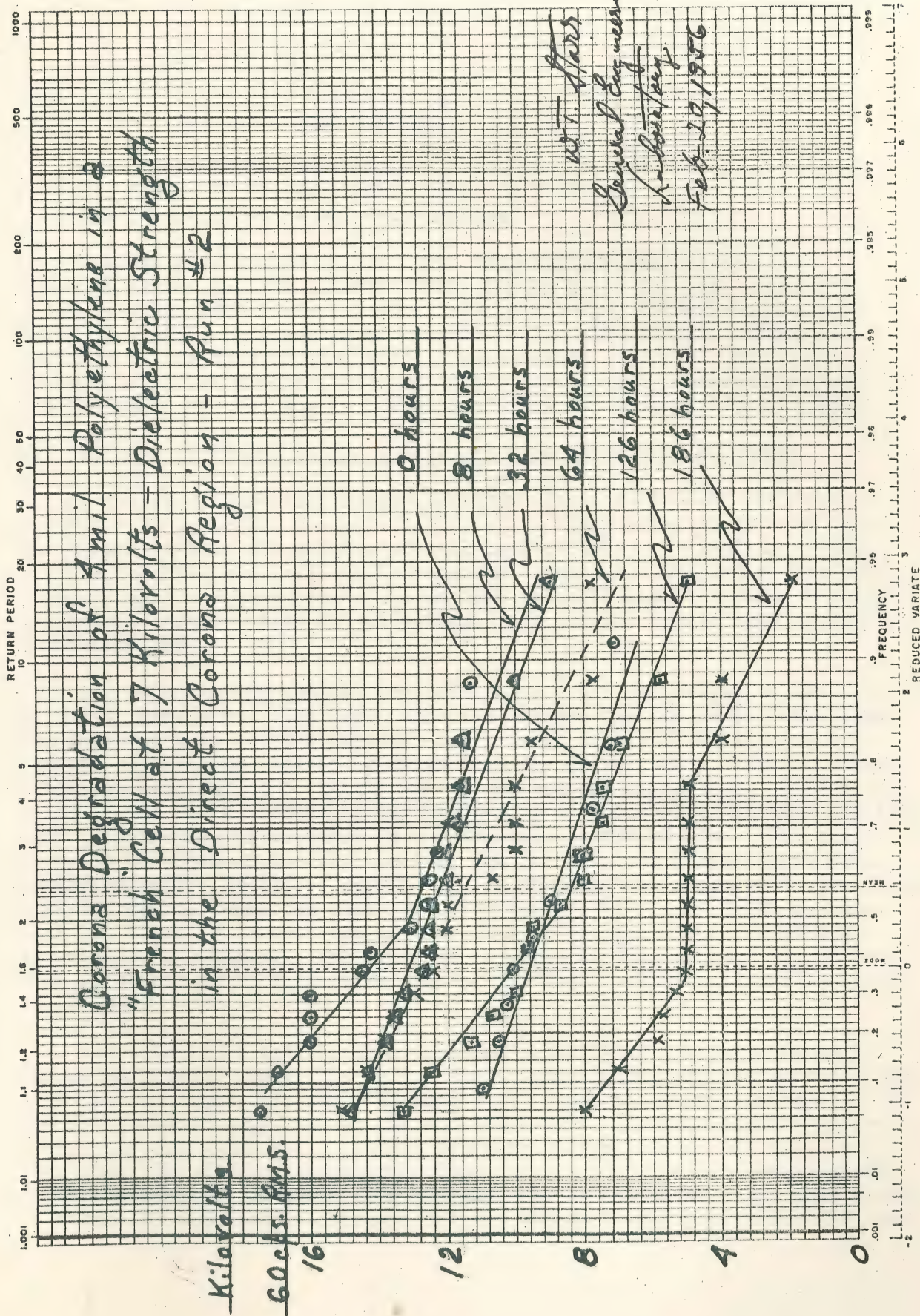
Figure 14

sidered constant due to the motion of air and these interactions will be expected even in refined designs.

See Figure 16 for 1 mil Mylar
See Figure 19 for Varnished Cloth
See Figure 14 for 4 mil Polyethylene

Several photographs of the 8 mil polyethylene samples used are shown in Figure 15. The direct corona region is at the top. The black spots are the results of dielectric strength tests. These samples have a definite smell reminiscent of butyric acid. The samples develop a definite yellow tint in the direct corona region. Chemical tests are planned to define whether the chromophore development is associated with the formation of nitrates by reaction of free radicals with nitric acid.

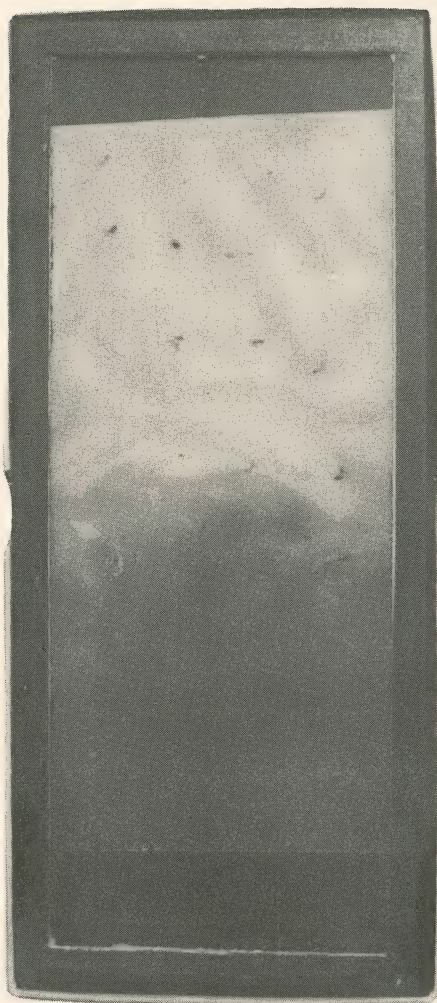VII Effects of Corona on the Electrical Properties of 1 mil Mylar

A series of experiments have been run with the "French" cell on 1 mil Mylar to determine the effects of cell voltage upon the rate of degradation and to test the effects of cell construction. A sampling of the results to show these effects is shown on Figure 16. The individual breakdown voltages are here plotted on extreme value probability paper because dielectric strength data fit an extreme distribution better than a normal (Gaussian) one.

The humidity and ambient temperature were not controlled on the 7.5 kilovolt tests since they were conducted outside the air conditioned room. The difference in audible corona level between 6.65 and 7.5 kilovolts in the air conditioned room is so large that the difference in rates of degradation is believed to be mainly due to the voltage difference. 6.65 kilovolts is too low a voltage and 7.5 kilovolts is about right in that significant degradation is produced in a reasonable period of time. The sharp increase in slope of the right end of the 7.5 kilovolt plots is probably connected with a localized degradation as observed and recorded in the first interim report. When the electrodes for the dielectric strength measurement lie close to or over one of the spots of accelerated degradation, a low result is obtained. The decrease in slope at 950 volts of one 72 hour plot, probably is an indication that a limiting breakdown voltage is being approached.

The effects of cell construction are actually effects of changes in thermal gradients within the cell. The original parallel cell construction as shown in Figures 17a and 17b, used 3 mil sheet aluminum electrodes. In the new construction, Figures 18a and 18b, 40 mil aluminum electrodes are used. The new construction allows air circulation between the cells and cuts down the hot spot temperature from 40 C to 30 C. All of the data up to this point were obtained with the old cell construction. The data shown in Figure 16 show some difference between the 24 hour degradations with the
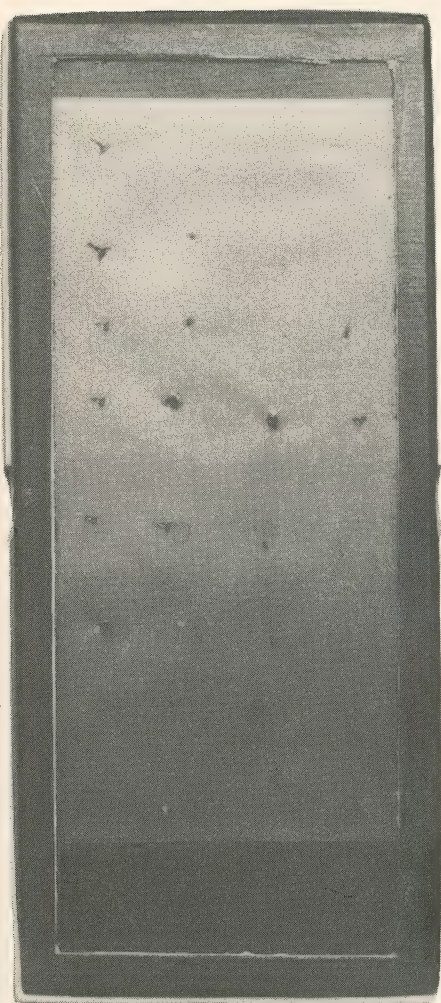
After 27 hours at
7 kilovolts

After 243 hours at
7 kilovolts
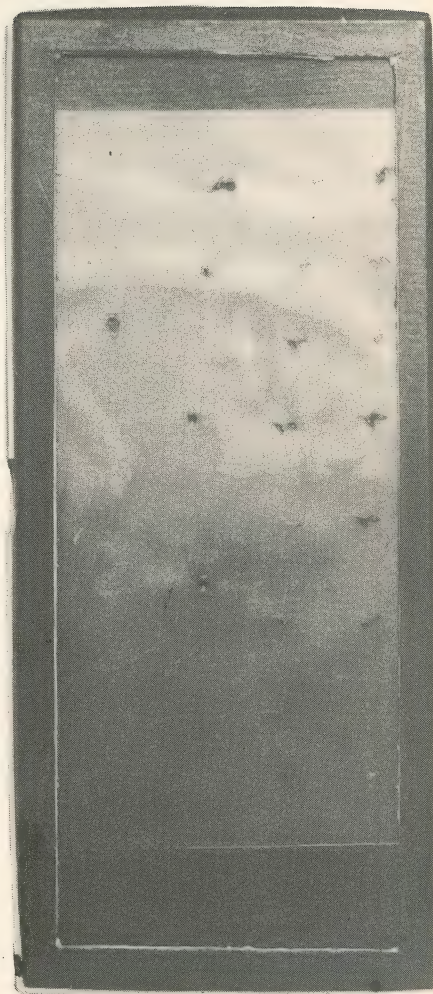
After 752 hours at
7 kilovolts

Figure 15

Dielectric Strength Deterioration of 1 mil Mylar Aged in "French" Cells under Various Conditions

Control - Unaged

24 hrs at 7 kv., 23° C, 50% R.H.
← Old Cell Construction

24 hrs } at 6.65 kv., 23° C.
72 hrs } 50 % R.H.

New Cell Construction

24 hrs } at 7.5 kv., 30° C, 30% R.H.
48 hrs }
72 hrs }

Kilovolts 60 cps RMS

Breakdown Voltage

W.T. Starr
General Engineering Laboratory
Feb. 20, 1956
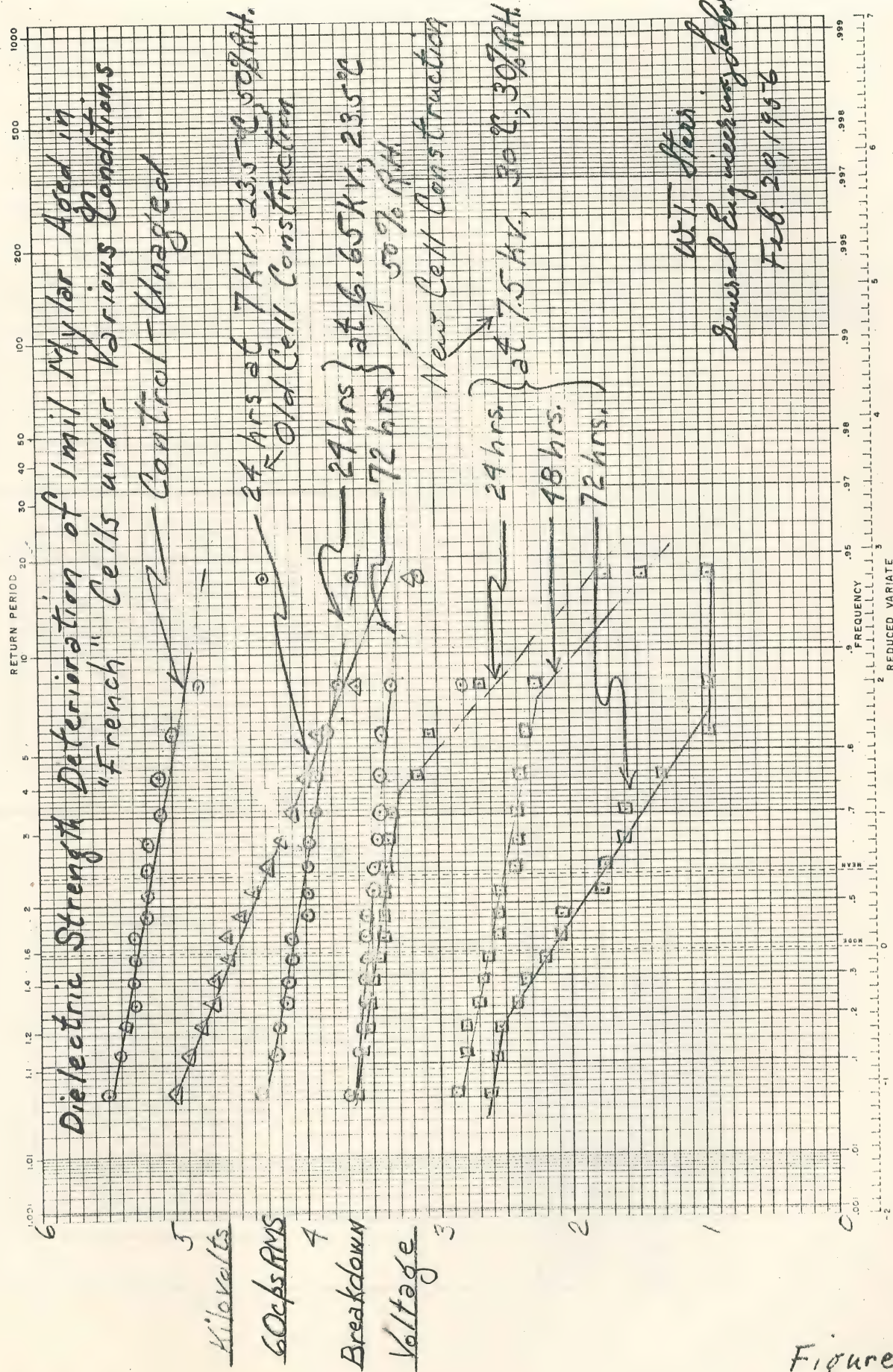
RETURN PERIOD

FREQUENCY
REDUCED VARIATE

Figure 16

Figure 16

new and old cell constructions, but the separation between the distri-
butions is not large enough to ascribe it to more than variability in
the Mylar. The physical degradation on the old test at 48 and 72 hours
was more pronounced as observed visually and by noting the sticking of
the Mylar in the cell.

The dielectric strength data in the corona by-product region of the
cell are included in the tables, but are not used for the analysis since
these tests are at present exploratory and the data in the direct corona
region have pointed the direction for future tests.

Figure 17

Figure 18

-21-
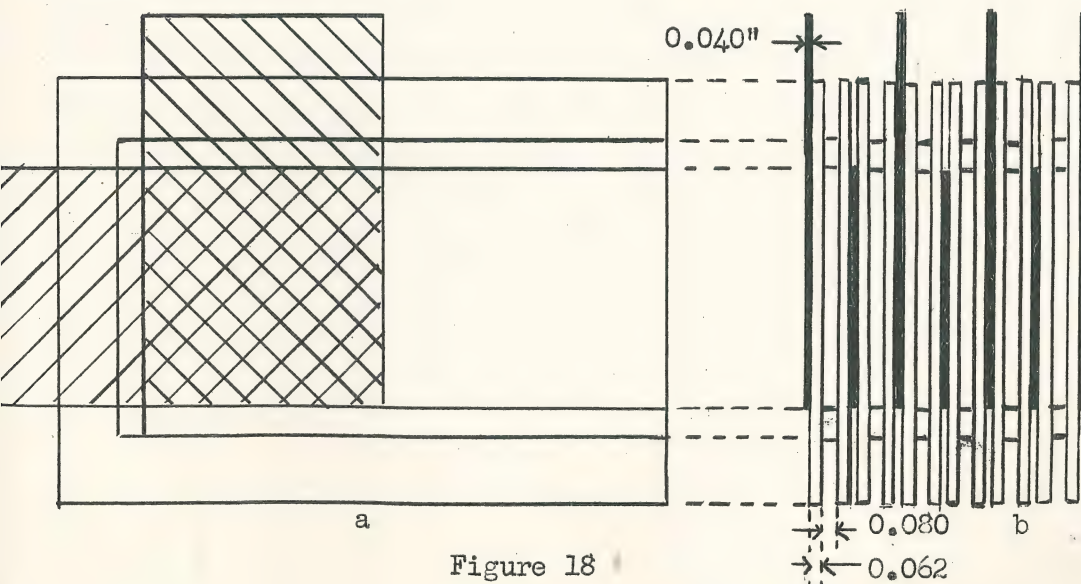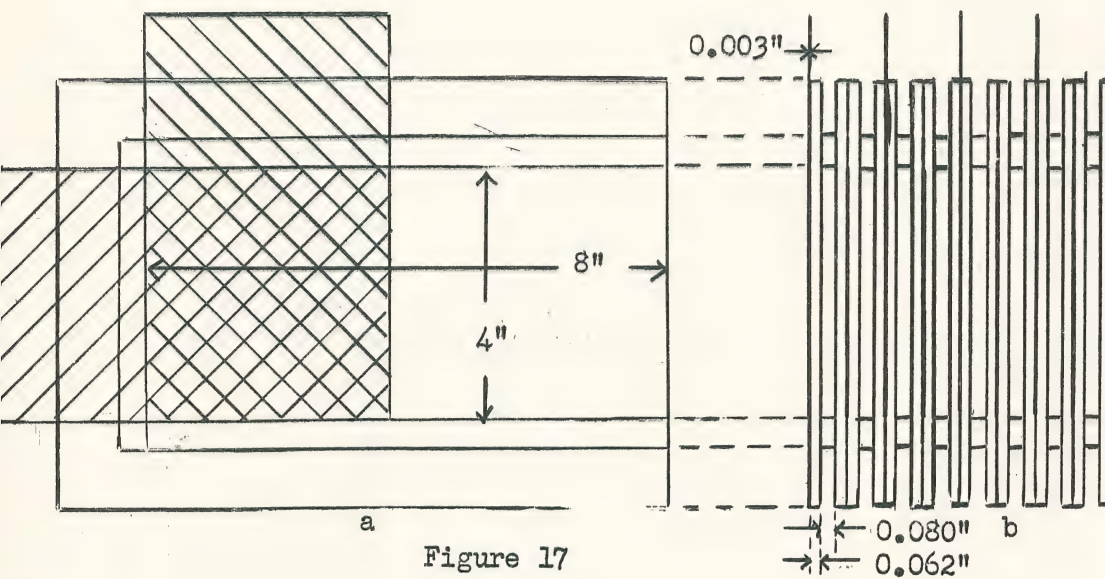
It is planned to determine the degradation rate at 7.5 kilovolts in the air conditioned room.

It is planned to measure the degradation rate in the "French" cell at 80°C.

Table 8

Dielectric Strength Tests on 1 Mil Mylar after Corona Aging in the "French" Cell

A

Old cell at 7 kilovolts in 23.5°C and 50% RH ambient

0 hrs. aging - Breakdown Kilovolts

Sample	1	2	3	4	5	6	7	8
A	5.30	--	5.20	--	4.30	--	5.40	--
B	5.00	--	5.30	--	5.20	--	4.80	--
C	5.10	--	5.40	--	5.30	--	5.10	--
D	5.20	--	5.50	--	5.30	--	5.20	--

24 hrs. aging

	Indirect corona effects				Direct corona effects			
A	5.20	5.00	5.10	4.00	4.40	4.50	4.30	4.60
B	4.90	5.20	4.10	4.90	3.60	4.10	4.80	4.70
C	XX	XX	XX	5.00	3.90	4.00	4.70	4.90
D	5.60	5.60	4.60	5.40	4.20	3.20	5.00	4.60

XX Sample Damaged during extraction from cell.

B

New cell at 6.65 kilovolts in 23.5°C and 50% RH ambient

24 hrs. aging

	Indirect corona effects				Direct corona effects			
A	5.15	4.36	3.77	4.02	4.13	3.84	4.13	4.16
B	4.44	4.18	4.29	4.16	3.91	4.20	3.98	3.64
C	5.34	4.95	3.91	4.44	3.72	4.00	4.25	4.35
D	5.49	5.56	5.29	4.69	4.12	3.98	3.97	3.92

48 hrs. aging

Sample	Indirect corona effects				Direct corona effects			
	1	2	3	4	5	6	7	8
A	4.73	4.43	4.22	4.03	3.78	3.79	3.68	3.64
B	4.34	4.26	3.42	3.64	3.64	3.73	3.82	3.55
C	4.59	4.45	3.70	3.77		3.73		
D	4.03	4.26	4.16	4.10	3.62	3.75	3.57	3.65

72 hrs. aging.

	1	2	3	4	5	6	7	8
A	3.49	3.84	3.66	3.72	3.62	3.42	3.43	3.58
B	4.05	4.03	3.75	3.82	3.50	3.55	3.56	3.46
C	4.50	3.83	3.98	3.98	3.15	3.56	3.60	3.60
D	3.78	4.13	3.86	3.88	3.34	3.42	3.67	3.48

C

New cell at 7.5 kilovolts in (approximate) 30°C and 30% RH ambient

24 hrs. aging in uncontrolled atmosphere

	1	2	3	4	5	6	7	8
A	3.84	3.25	3.88	3.82	3.40	3.52		
B	3.61	3.35	3.42	3.81		3.35	3.46	3.42
C	4.25	3.56	3.71	3.71	3.54	3.38	3.41	3.42
D	5.22	4.14	4.34	4.18	3.64	3.54	3.62	

49 hrs. aging in uncontrolled atmosphere

	1	2	3	4	5	6	7	8
A	4.43	4.52	4.35	4.06	2.54	2.54	2.39	2.40
B	4.21	4.22	4.06	4.14	2.56	2.82	2.71	2.27
C	5.36	4.27	4.29	4.16	2.41	2.42	2.64	2.83
D	6.11	5.76	4.56	4.22	2.33	2.63	1.44	2.89

72 hrs. aging in uncontrolled atmosphere

	1	2	3	4	5	6	7	8
A	4.52	4.01	3.53	3.48	2.37	2.54	2.42	2.08
B	4.11	3.96	3.68	3.40	0.96	0.96	1.79	2.58
C	4.65	4.15	4.40	3.48	1.74	1.60	0.98	1.32
D	5.06	4.26	3.63	3.67	2.21	1.59	2.08	2.64

VIII   The Effects of Corona on Moisture Pick Up.

Corona produces free radicals and ions on the surface of organic insulations which can attract moisture. It also produces acids, alde-hydes and many other degradation products which are hydrophilic. Corona produces heat. The amount of moisture absorbed will be a measure of the balance between these three factors.

If the balance favors moisture absorption this fact becomes very important in defining corona resistance of materials. A few exploratory tests were made at 50% relative humidity and 23.5 C.

Three materials were selected. Polyethylene was chosen because it has very little moisture absorption and develops acids which may be some-what hygroscopic at 23.5 C and 50% RH. Mycalex was chosen because it would be a good control. Epoxide 828 with CL hardener was chosen because it had a measureable moisture absorption at 23.5 C and 50% RH.

Squares of these materials 3" x 3" x 0.10" were conditioned for one week at 23.5 C and 50% RH. They were then wrapped carefully in aluminum foil and weighed to the tenth of a milligram. The aluminum foil was re-moved next and the samples were placed on two inch diameter stainless steel electrodes. Another electrode, one inch in diameter and 1/8 inch edge radius was placed on the surface of the insulation. Ten kilovolts was then applied for 24 hours. The samples were removed quickly, re-placed in their original Al wrappers and reweighed. Then the samples were allowed to condition 24 hours at 23.5 C and 50% RH. After this they were again weighed. Finally, the samples were placed over silica gel and dried for 24 hours. Then they were given their final weighing. The data are given in Table 9

Table 9

Milligrams change in Wt. from Original

Material		After 24 hrs. of Corona	After 24 hrs. at 23.5 C 50% RH	After 24 hrs. of Drying
Polyethylene	1	+ 2.0	+ 2.0	+ 1.9
	2	+ 1.7	+ 1.5	+ 1.4
Epoxide 828-CL	1	− 1.0	+ 1.3	−31.0
	2	− 0.6	+ 1.5	−29.5
Mycalex	1	0.0	0.0	0.0
	2	0.0	0.0	0.0

If we assume a possible error of = 0.2 mg the following statements can be made

1. The degradation products of polyethylene contain no water and are not hygroscopic at 50% RH 23.5 C.

2. There is no effect on Mycalex.

3. Corona drives moisture out of Epoxide 828 with CL hardener.

IX Power Factor and Dielectric Constant of Contract Materials (A.W.Soris)

Power factor, dielectric constants, and specific resistivities of several of the contract materials, measured at 60 cps and at several temperatures, are shown in Table 10.

The data, except for one small part, are self explanatory. The increase in resistivity of Micamat Silicone Resin with increasing temperature is not conventional. It is believed that some decrease in moisture content with increasing temperature is, in large part, the cause of this unexpected behavior.

References:

1. (a) Effects of Electric Discharges on the Breakdown of Solid Insulation
        Dakin, T. W.; Philofsky, H. M.; Divens, W. C. Trans. A.I.E.E. 73, Part 1, 155 (1954) (May) Sci. Ab. B, #4087 (1954)

    (b) Dielectric Breakdown of Polymers Under Prolonged Stress
        Brodhun, Carl
        Phys. Rev. 86, 653A (1952)
        Sci. Ab. A, #4086 (1952)

    (c) The Breakdown of Dielectrics by Electric Discharges
        Thomas, A. M.; ERA Report L/T 191 (1949)

    (d) Breakdown of Insulation by Discharges
        Mason, J. H.; Proc. I.E.E. 100 Pt. IIA (1953)

Table 10

	Dielectric Constant				Power Factor %				Resistivity (ohm cm)			
	25C	50C	100C	150C	25C	50C	100C	150C	25C	50C	100C	150C
Silicone Glass Laminate G.E. 11523	3.9	3.9	3.8	3.8	0.15	0.16	0.19	0.24				1.0×10^{14}
	3.9	3.9	3.9	3.8	0.15	0.15	0.18	0.20				2.7×10^{14}
Silicone Glass Laminate G.E. 11514	4.0	4.0	4.0	3.9	0.16	0.18	0.23	0.30				1.2×10^{14}
	4.0	3.8	3.7	3.7	0.17	0.19	0.22	0.26				1.8×10^{14}
Micamat-Silicone Resin G.E.77103 (1/16" thick)	5.6	5.8	4.7	4.4	15	15	6.6	3.9	3.3×10^{12}	2.3×10^{13}	3.3×10^{13}	
	5.5	5.7	4.7	4.2	13	13	6.2	1.6	6.6×10^{12}	2.0×10^{13}	6.6×10^{13}	1.8×10^{13}
Paper Pheonlic Laminate G.E. 11564	5.3	5.8	9.3		5.0	14	42		7.6×10^{12}	9.7×10^{11}	1.6×10^{11}	
	5.3	5.7	8.6		4.8	13	38		8.3×10^{12}	12×10^{11}	2.9×10^{11}	
Melamine Glass Laminate G.E. 11512	12	15	26		24	32	51		6.3×10^{11}	1.3×10^{11}	3.9×10^{11}	
	11	14	20		21	29	41		9.1×10^{11}	1.5×10^{11}	1.8×10^{11}	
Polyvinyl Chloride Geon 8700	3.9	4.1	10		1.8	2.7	16	93			7.4×10^{11}	5.3×10^{9}
	3.9	4.1	99		1.8	2.6	15	57			7.5×10^{11}	9.7×10^{9}
Rubber Modified Polystryene Lustrex 88	2.8	2.8	2.8		0.076	0.074	0.077	0.38				
Teflon (Extruded) 5.2 mils	2.0	2.0	2.0	2.0	0.038	0.031	0.031	0.055				
	2.0	2.0	2.0	2.0	0.038	0.031	0.031	0.026				
Teflon (Cast 2 mils	2.0	2.0	2.0	2.0	0.11	0.11	0.11	0.081				
Epoxide 828 with CL Hardener	5.3	5.5	6.8	6.8	1.6	2.9	12	14			1.5×10^{12}	4.4×10^{11}
	5.6	5.8	7.0	7.2	1.7	3.0	12	15			1.3 "	3.0 "

Figure 19

Breakdown Voltages for Varnished Cloth #17998

Time at 7 kilovolts in the "French" Cell

W.T. Starr
Gen. Eng. Lab
Gen. Elec. Co.
Mar 1 1956

0 hrs

63 hrs.

110 hrs.

205 hrs.

kilovolts
60 cps, Rms.

Figure 19